2 Recording electrodes

SUMMARY

Recording electrodes transfer electrical potentials at the recording site to the input of the recording machine.

(2.1) **Electrode types** most commonly used in clinical EEG are metal discs or cups attached to the scalp and other recording sites. Needle scalp electrodes are no longer recommended for routine clinical use. Nasopharyngeal and sphenoidal electrodes require special insertion procedures and are used in some laboratories in addition to scalp electrodes in an attempt to record the EEG from the undersurface of the temporal lobe.

(2.2) **Electrical properties** determine whether recording electrodes can couple potential changes from the head to the input of the EEG machine without distortion. Electrodes should have a surface made of gold, chlorided silver or other materials that do not interact electrically with the scalp. Electrode application should create an electrical contact with impedances between 100 and 5000 Ω. Electrodes with much higher impedances can attenuate the recording and cause 60 Hz artifact; impedances of less than 100 Ω are usually the result of accidental short-circuits between electrodes. Polarization and bias potentials develop at the interface between electrode and tissue and can be minimized by careful technique and the use of proper electrode metals.

(2.3) **Placement of electrodes** should cover the entire head evenly and be reproducible between subjects and laboratories. This is accomplished using the international 10–20 system or more recently, the modified 10–20 system. The 10–20 system uses measurements between bony landmarks on the skull to determine the coordinates for 21 recording electrodes. The modified 10–20 system duplicates the 10–20 system but has provisions for additional electrodes and is now the preferred system of electrode placement. Fewer electrodes may be used in infants.

(2.4) Recording non-cerebral potentials is useful for detecting and identifying artifacts that contaminate the EEG as well as for monitoring other body functions such as eye movements, axial muscle tone, respiration, and motor activity. Whenever the technologist encounters spontaneous abnormal movements, additional electrodes or monitors should be placed that will display the movements and allow them to be correlated with the ongoing EEG.

2.1 ELECTRODE SHAPES AND APPLICATION METHODS

Electrodes consist of a conductor attached to a wire that leads to a plug that is inserted into the input of the recording machine. Scalp electrodes are applied after determining their precise scalp location and after preparing the scalp to reduce electrical impedance. Metal surface electrodes should be cleansed with a solution of an antiseptic soap after each use. Nasopharyngeal electrodes should be autoclaved; penetrating electrodes used on patients with contagious diseases should be discarded after use. Special handling and cleaning procedures must also be used for surface electrodes in patients at special risk for contagious diseases such as AIDS, viral hepatitis or Creutzfeldt–Jakob disease.

2.1.1 **Metal disc and cup electrodes** usually have diameters of 4–10 mm (Fig. 2.1). Smaller or larger electrodes do not make stable mechanical and electrical contact with the scalp. An insulated lead wire is attached to each electrode. The insulation of each wire has a different color for easy identification of each electrode. Mechanical and electrical problems are reduced if the insulations of the lead wires are attached to each other in the form of a stranded cable from which the leads separate only at the two ends. Before electrodes are applied, the application site is determined by measurements (2.3) and prepared by wiping with alcohol or abrasive electrolyte gels (such as Omni Prep).

Several methods may be used to attach electrodes to the scalp. The collodion technique has the advantage of giving very stable recordings with relatively few artifacts. It is the only available method for long term recording. In this technique, cup electrodes with a central hole are placed onto the prepared scalp site and held in place with a stylus while a few drops of collodion are applied around the edge of the elec-

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Fig. 2.1. Various types of extraocular EEG electrodes, shown with their connector plugs and part of their lead wires. (a) Large metal cup electrode with a central hole. (b) Large metal cup electrode without hole. (c) Small metal cup electrode with central hole. (d) Clip electrode. (e) Needle electrode. (f) Nasopharyngeal electrode.
trode and spread onto the scalp. The spreading and drying of the collodion may be facilitated by a stream of compressed air guided through a tube around the stylus. After the electrode is securely attached, the stylus is removed and the cup is filled with conductive jelly which is injected with a blunt hypodermic needle inserted through the central hole of the cup. If cup electrodes without a central hole are used, they are filled with conductive paste before application to the scalp. Some laboratories place small pieces of gauze soaked with collodion over the electrodes to hold them in place. Electrodes are removed by dissolving the collodion with acetone. Because of the chemicals involved, the collodion method should not be used in areas that have limited ventilation or explosion hazards such as infant islets or operating rooms.

Another method of applying electrodes uses a paste that can both hold the electrode in place and provide good electrical contact. After preparation of the scalp site, a piece of this adhesive conductive paste is placed on the scalp and the electrode is pressed into the center of the paste until it makes firm contact. Electrodes with a central hole allow the paste to escape through the hole so that the rim of the cup sits firmly on the scalp. A gauze pad or cotton ball may be placed over the electrode to hold it more securely in place and to delay drying of the paste. This method is fast, but electrodes tend to lose good mechanical and electrical contact more readily than when they are applied with collodion.

Other methods of applying disc or cup electrodes involve the use of: (a) paraffin wax, (b) suction electrodes, or (c) headbands, straps or caps which hold an entire set of electrodes in place. These methods generally give less satisfactory results than the other methods described above.

Metal disc or cup electrodes may be placed around the eyes, on the chest or other parts of the body to monitor electrical potentials which are generated by eye movements, heart beat, respiration, muscle contraction or body movements that often contaminate the EEG (4.3). While EEG scalp electrodes may be used to monitor the occurrence of extracranial activity, they introduce some distortion and special electrodes are required if faithful recordings of such activity are desired.

2.1.2 *Clip electrodes* are sometimes used for recordings from the earlobes. The clips should contain cups or discs made from the same materials as the scalp electrodes to avoid electrical problems caused by recording from dissimilar electrodes.

2.1.3 *Needle electrodes* are sharp wires, usually made of steel or platinum. They are inserted into the superficial layers of the scalp after thorough disinfection of the insertion site. The advantage of fast application is outweighed by the disadvantages of pain, possible infection and unfavorable electrical characteristics. Some laboratories still use these electrodes for emergency recordings from comatose patients, but most electroencephalographers feel they should not be used. Needle electrodes are frequently used during intraoperative recordings and in association with intracranial electrode recording.

2.1.4 *Nasopharyngeal electrodes* are used in addition to scalp electrodes by some laboratories in patients who are suspected of having epileptiform activity in the basal parts of the temporal lobe but who do not show such activity in scalp recordings.

Nasopharyngeal electrodes are made of a conducting wire embedded in rigid plastic that has a Z-shape to fit the path of insertion. The tip is an uninsulated 2–5 mm diameter metal ball. One electrode is inserted through each nostril, slid backwards along the bottom of the nasal cavity near the midline, and then rotated outward. This places the tip against the roof of the nasopharynx and very close to the skull at the base of the middle cerebral fossa, i.e. close to the tip of the temporal lobe. Because the insertion can cause discomfort, gagging and slight injury to the mucous membranes, it is often done by a physician using a local anesthetic spray.

It is important to recognize that nasopharyngeal electrode recordings occasionally produce artifacts that mimic epileptiform spikes and sharp waves. Thus, epileptiform activity occurring exclusively at the nasopharyngeal electrode should be considered artifact until proven otherwise. The main advantage of nasopharyngeal recordings is to emphasize or clarify activity also recorded at other electrode sites. In this regard, however, it is also important to recognize that certain benign patterns, such as small sharp spikes, may be greatly amplified by nasopharyngeal recordings. This amplification frequently leads readers unfamiliar with nasopharyngeal recordings to mistakenly identify pseudoepileptiform patterns as abnormal epileptiform patterns.

2.1.5 *Sphenoidal electrodes* are used to detect epileptiform activity in the temporal lobes. This electrode consists of a flexible wire with an uninsulated tip which is placed near the sphenoidal wing through a cannula inserted through the temporal and masseter muscles. Electrode placement can be checked by X-ray. The electrodes can be left in place for several days of serial EEG recordings without danger of breaking or injury to the patient. (For a more detailed explanation of electrode placement refer to the references at the end of the chapter.)

Sphenoidal electrodes are mainly of value for distinguishing between mesial and lateral temporal epileptogenic sources. They rarely increase the likelihood of detecting temporal epileptiform discharges, particularly if surface electrodes recorded with long interelectrode distances are placed near the sphenoidal electrode insertion points, or if so-called true anterior temporal surface electrodes are used (2.3.2). Their usefulness is mainly due to the typical distribution of temporal lobe epileptiform spikes, shown in Fig. 2.2.

2.1.6 *Electroocorticographic ball or wick electrodes* are used during some neurosurgical procedures, usually excision of epileptogenic foci, to record the ECoG from the exposed cortical surface. These electrodes consist of metal balls or saline-soaked cotton wicks which may be mounted on springs and held in place by swivel joints for easy placement.
2.1.7 **Subdural and epidural electrodes** are used to localize epileptiform activity and to map cortical function. They consist of sheets or single column strips of evenly spaced disc electrodes (usually made of platinum or stainless steel) embedded in a thin layer of flexible translucent Silastic rubber. The sheets are inserted through a craniotomy opening, whereas the strips consisting of single rows of electrodes can also be introduced into the epidural or subdural space through a burr hole. Once the electrodes are in place, the underlying cortical activity can be recorded by connecting the electrode leads to the input board of any routine EEG machine. In addition, the subdural electrodes can be used to stimulate the underlying cortex by applying an electrical current to individual electrodes. The results of stimulation, which typically include involuntary movements, sensory manifestations, or various forms of aphasia, are used to map the locations of critical cortical functions so they may be spared during cortical resection.

2.1.8 **Depth electrodes** are used for EEG recording, to define the targets for surgical destruction, and for placement as stimulating electrodes for the treatment of movement disorders. EEG recording depth electrodes consist usually of a bundle of fine wires that terminate at different cylindrical contacts along the length of the depth electrode and thus allow for recordings from different depths. As with subdural electrodes, platinum metal is used for MRI compatability. The insertion of depth electrodes is stereotacically guided by determining the position of the target in a three-dimensional reference system using a frame attached to the head. The trajectory coordinates of the head frame are matched to MRI and CT images for precise placement into targeted brain structures. So-called ‘frameless’ stereotaxy currently lacks precision for the routine implantation of depth electrodes.

2.2 **ELECTRICAL PROPERTIES OF RECORDING ELECTRODES**

Good recording electrodes should couple the electrical potential changes at the recording site to the input of the recording machine without distortion. To obtain such high fidelity recordings, one must (1) choose recording electrodes of suitable material; (2) measure electrode resistance to ascertain electrical continuity between the two ends of the electrode if in doubt; (3) measure electrode impedance after every electrode application and during the recording to evaluate the electrical contact between electrode and scalp; and (4) avoid electrode polarization and bias potentials.

2.2.1 **Electrode materials** should be those which do not interact chemically with the electrolytes of the scalp. Electrodes coated with gold, silver chloride, tin or platinum are satisfactory.

2.2.2 **Electrode resistance**, or opposition to direct current.

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Fig. 2.2. The stippled area shows the approximate distribution of right temporal lobe epileptiform spike activity over the surface of the head. Note that the best areas for recording are behind the outer canthus of the eye, over the area of the inferior zygomatic arch (where sphenoidal electrode insertion is located), superior to the zygomatic arch (where so-called true anterior temporal electrodes are placed) and immediately anterior to the ear (the auricular electrodes A1 and A2 often detect a higher amplitude spike than do F7 and F6). Reproduced from Gibbs and Gibbs, 1952.
flow, is measured when a break in the electrical continuity between electrode, lead wire and connector plug is suspected. This measurement is made while the electrode is not attached to the scalp. The two uninsulated ends of the electrode are connected to an ohmmeter which passes a weak direct current through the electrode. The resistance of an intact electrode should measure no more than a few ohms.

2.2.3 **Electrode impedance**, or opposition to alternating current flow, is measured after an electrode has been applied to the recording site to evaluate the contact between electrode and scalp. The impedance of each electrode should be measured routinely before every EEG recording and should be between 100 and 5000 Ω. Electrode impedance is measured with an impedance meter that passes a weak alternating current from the electrode selected for testing through the scalp to all other electrodes connected to the meter (Fig. 2.3). The measured impedance reflects mainly that of the selected electrode, the other electrodes offering multiple return pathways with negligible total impedance.

An alternating current is used for this measurement for two reasons: (a) Alternating current is more representative of the alternating potential changes recorded in the EEG, especially if it alternates at about 10 Hz, a common frequency of EEG potential changes; the opposition to current alternating at this frequency may differ from that to alternating current of other frequencies and, especially from that to direct current. (b)

Passage of direct current through an electrode attached to the scalp can electrically polarize the interface between electrode and skin and thereby lead to distortion of subsequent EEG recordings.

Most EEG machines have provisions for testing electrode impedance during the recording. This is done by injecting a weak alternating current of constant intensity through a pair of electrodes connected to the input of a recording channel. This causes a pen deflection in that channel with an amplitude proportional to the sum of the impedances of the two electrodes. If the deflection indicated has an unacceptably high or low impedance, the faulty electrode of the pair must be identified by pairing each electrode with another electrode of acceptable impedance and repeating the current injection.

Very high or very low impedance is undesirable. Very low impedance acts like a shunt between the recording electrodes and effectively short-circuits the EEG potential differences. It is practically impossible to reduce electrode impedance to less than a few hundred ohms without there being an abnormal pathway of conduction between the electrodes across the scalp. An electrode showing very low impedance may be making contact with another electrode because of an excess of electrolyte jelly or paste, or because of saline or sweat forming a conductive bridge between the electrodes on the scalp. Such an electrode should be inspected, cleaned, and reapplied or exchanged if necessary.

Very high impedance is undesirable mainly because connecting an electrode of very high impedance and one of lower impedance to the input of a differential amplifier causes an imbalance which favors the recording of 60 Hz interference*. (3.4). Electrodes showing high impedance readings should be checked for good mechanical and electrical contact and the junctions of the lead wire with the metal disc or cup and with the plug terminal should be inspected for possible breaks.

2.2.4 **Electrode polarization and bias potentials** may occur

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* Interference has a frequency of 50 Hz in countries using alternating current of that frequency.

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![Fig. 2.3. Measurement of electrode impedance. (a) Diagram of the input board with receptacles for the connectors from scalp electrodes (left), selector switch designating electrode Fp2 for impedance measurement (middle), and impedance meter (right). (b) Electrical circuit used for impedance measurement: a weak alternating current is passed through the impedance meter to the electrode selected for measurement (Fp2) and its contact with the scalp (not shown); the current is returned through a combination of all other scalp electrodes. The impedance of the selected electrode is read from the impedance meter; the impedance of the return path is negligible relative to that of the electrode being tested.](image-url)
of alternating EEG potentials. Polarization is kept to a minimum by: (a) a fairly large contact area between electrode and scalp that keeps current density at any one point low; (b) high impedance amplifier inputs that keep the current (amperage) flowing through the electrodes during the recording low; and (c) avoidance of steady current flow, especially that used to measure electrode resistance. With these precautions, it is not necessary to use non-polarizable electrodes such as chlorided silver electrodes for routine clinical EEG recordings, although such electrodes are necessary for other purposes, especially for faithful recording of very slowly changing or steady potential differences.

**Bias potentials** result from the exchange of metal ions and electrolytes in the absence of current flow. They interfere with EEG recordings only when they are not steady. Steady bias potentials cause blocking of amplifiers that occurs in analog EEG instruments immediately after switching to a new selection of electrodes. The effect of bias potentials can be minimized by using (a) electrodes of pure metals with clean surfaces which reduce ion exchange and (b) electrodes of the same kind at the inputs of each amplifier; this neutralizes electrical differences caused by bias potentials.

### 2.3 Electrode Placement

#### 2.3.1 The international 10–20 system

Electrode placement provides for uniform coverage of the entire scalp. It uses the best made with a metric measuring tape of cloth or plastic. A grease pencil is used to mark electrode locations and the intermediate measurements needed to determine them. The measurements refer to three bony landmarks of the skull: (1) the inion, or the bony protruberance in the middle of the back of the head, (2) the nasion, or the bridge of the nose directly under the forehead, and (3) the preauricular point, or the depression of bone in front of the ear canal. Measurements are made in a sequence of five steps (Fig. 2.4). Although the older nomenclature of the 10–20 system is used in the following description, readers are encouraged to adopt the newer terminology of the modified 10–20 system in which T3 and T4 are renamed T7 and T8 and T5 and T6 are renamed P7 and P8.

**Step 1:** The distance between nasion and inion is measured along the midline. Along this line, the frontopolar point, Fp, is marked at 10% above the nasion. Frontal (Fz), central (Cz), parietal (Pz) and occipital (O) points are marked at intervals of 20% of the entire distance leaving 10% for the interval between O and inion. The midline points Fpz and Oz are used only for intermediate measurements but routinely receive no electrode.

**Step 2:** The distance between the two preauricular points across Cz is measured. Along this line, the transverse position for the central points C3 and C4 and the temporal points T3 and T4 are marked 20% and 40% respectively from the midline.

**Step 3:** The circumference of the head is measured from the occipital point (O) through the temporal points T3 and T4 and the frontopolar points Fp. The longitudinal measurement for Fpl is located on that circumference, 5% of the total length of the circumference to the left of Fpz. The longitudinal measurements for F7, T3, T5, O1, O2, T6, T4, F8, Fp2 are at distances of 10% of the circumference.

**Step 4:** The longitudinal distance from Fpl and Fp2 through C3 and C4 to O1 and O2 is measured on each side. The midpoints of these distances give the longitudinal coordinates of C3 and C4. The midpoints between Fpl and C3 on the left, and Fp2 and C4 on the right give the longitudinal coordinates for F3 and F4. The midpoints between C3 and O1 on the left, and C4 and O2 on the right give the longitudinal coordinates for P3 and P4.

**Step 5:** Measurements from F7 to F8 through Fz define the transverse coordinates for F3 midway between F3 and Fz, and for F4 midway between Fz and F8; measurements from T5 to T6 through Pz define the transverse coordinates for P3 midway between T5 and Pz and for P4 midway between Pz and T6.

Electrodes are placed at Fz, Cz and Pz, at all lateral points designated above, on or near both ears in positions called A1 and A2 or on the mandibular angles (4.2.4) in positions called M1 and M2, and on the point chosen for the ground electrode, usually in the middle of the head or over one of the mastoids. The use of a smaller number of electrodes in routine EEG is
now considered substandard. If needed, additional electrodes may be placed midway between these recording electrodes. In some cases, scalp lesions, skull asymmetries or other abnormalities may make it impossible to place electrodes in the positions of the 10–20 system. In these cases, electrodes should be placed as closely as possible to these positions and as symmetrically as possible on the two sides using the modified 10–20 system of placement. The deviations from standard placement should be indicated in a diagram on the EEG record. Other electrode placements may be used for EEG recordings from small infants and for monitoring of extracerebral activity such as eye movements, heart beat, respiratory or other movements (4,3).

2.3.2 True anterior temporal electrodes. Because interictal epileptiform activity frequently emanates from the anterior temporal lobe, some laboratories occasionally use additional electrode placements that are closer to the anterior temporal region than F7 and F8 (see Fig. 2.2 for the typical distribution of anterior temporal spikes). Often these are placed according to the recommendation by Silverman (1960) and are referred to as true anterior temporal electrodes. Although these electrodes are often labeled as T1 and T2, according to the international 10–20 system, T1 and T2 would be placed between F7 and T3, and F8 and T4, respectively. The positions for so-called true anterior temporal electrodes are located by first finding an imaginary line between the external auditory canal and the lateral canthus of the eye. The point along that line that is anterior to the external auditory canal by 1/3 the distance of the total line is then located. The electrode is placed 1 cm directly above that point.

2.3.3 Modified 10–20 system. The placement of additional electrodes to those routinely employed in the 10–20 system may be indicated to: (1) improve the localization of ictal or interictal epileptiform activity; (2) increase spatial resolution for special studies using computerized EEG signal analysis; or (3) detect highly localized evoked potentials. The American Clinical Neurophysiology Society has developed new guidelines for extending the 10–20 system of electrode placement. In order to create a logical nomenclature, four electrodes, T3, T4, T5 and T6, have been renamed T7, T8, P7, and P8, respectively (Fig. 2.5). The American Clinical Neurophysiology Society guidelines that explain renaming of these electrodes and the placement of the additional electrodes have been reproduced in Appendix II.
2.4 RECORDING NON-CEREBRAL POTENTIALS

2.4.1 *Eye movements* are often monitored so that they can be distinguished clearly from frontal or anterior temporal cerebral potentials. Eye movements are usually recorded in two channels; monitoring in one channel is less reliable. If two channels are available, one electrode is placed slightly above and to the side of one eye and connected to input 1 of the first channel (E1). A second electrode is placed slightly below and to the side of the other eye (E2) and connected to input 1 of the second channel. Input 2 of both channels is connected to the same reference electrode on the ear or mastoid (e.g., E1–A2 and E2–A2). This arrangement of electrodes forces all eye movements to produce pen or waveform deflections in opposite directions (phase reversals, 4.2) between the 2 channels of recording, whereas any deflections that are in the same direction do not arise from eye movement. If only one channel is used for monitoring of eye movements, electrodes E1 and E2 are connected to input 1 and input 2 of that channel. The recording will not distinguish between horizontal and vertical eye movements or between eye movements and EEG.

Eye movement monitoring is also used to detect REM sleep during multiple sleep latency testing (MSLT; 7.7) and polysomnography (7.6). The finding of two or more REM episodes during separate naps of the MSLT is highly suggestive of narcolepsy when coupled with the appropriate clinical findings (e.g., daytime sleepiness and cataplexy). However, distinguishing REM sleep from drowsiness or brief wakefulness during arousal from sleep can sometimes be difficult. Eye movement monitoring that differentiates lateral from vertical eye movements can help with this distinction because REM sleep usually contains prominent lateral eye movements, whereas arousal and wakefulness usually contain more prominent vertical eye movements. If one electrode is placed above and between the eyes (Fz), one electrode is placed below and to the right of the right eye (OD) and a third electrode is placed below and to the left of the left eye (OS), then these electrodes can be used to create the following 2 channels of recording: OD–Fz and OS–Fz. This arrangement of electrodes forces all lateral eye movements to produce deflections in the 2 channels that are opposite in direction whereas all vertical eye movements and frontal lobe EEG potentials will produce deflections in the 2 channels that are in the same direction.

2.4.2 *Heart beat* may be monitored by connecting an amplifier to an EEG electrode placed on the neck or the chest and to another electrode at some distance away. If electrodes with long lead wires are available, standard ECG electrode positions on the extremities may be used.

2.4.3 *Respiration* is best monitored by simultaneously recording respiratory body movements and air flow. Respiratory movement may be recorded with a piezoelectric crystal transducer belt placed around the chest and the abdomen, or in special circumstances a pressure-sensitive balloon in the esophagus may be used to monitor subtle intrathoracic pressure changes. Respiratory air flow is routinely monitored using thermal sensitive detectors taped under the nostrils that register air flow from both nose and mouth. While EEG electrodes cannot monitor respiration, they may be of some use in identifying ventilator artifact in EEG recordings. For this purpose, EEG electrodes attached to the patient may be taped or looped around parts of the respiratory equipment which move with respiration (e.g., the ventilator tubing). This should result in recording of movement artifact corresponding with inspiration and expiration.

2.4.4 *Muscle activity* can be monitored with EEG electrodes placed over the center of a muscle. To monitor tonic muscle activity in sleep, a channel is devoted to a pair of electrodes placed on the neck below the chin at equal distances of at least 1–2 cm from the midline. This provides a measurement of submental muscle tone and is useful for determining whether REM sleep (in which there is an absence of muscle tone and EMG artifact) is present. Needle electrodes inserted into a muscle may also be used to record local muscle activity that can be displayed on an EEG tracing within the limitations of the high frequency response or paper speed of an analog EEG instrument.

2.4.5 *Movement* caused by tremor, myoclonus or convulsive twitching may be monitored by electrodes placed on the moving body parts; such monitoring is likely to indicate the occurrence of movements, but the type of movement must be described on the recording by the technologist.

2.4.6 *Blood pressure, body temperature, eye position, blood oxygen saturation and other slowly changing or sustained activities* require special electrodes or transducers and can be recorded only with EEG instruments and polygraphs equipped with directly coupled amplifiers.

REFERENCES


